Estimation of hull forces in low-level still water manoeuvring mathematical models

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Relevance and questions

• Lower-level models for ship manoeuvring in waves contain the still-water component and are supposed to be reduced to it at zero wave amplitude

• Necessary for working out manoeuvrability criteria in wind

• Can be combined with hydrodynamic interaction models

• Question 1: What is the minimum acceptable complexity?

• Question 2: How reliable can be hull forces predictions?

• Question 3: Is it possible to make low-level estimates reasonably conservative?
3 DOF model

- Minimum recommended complexity:

\[
(m + \mu_{11})\ddot{u} - mnr - mx_G r^2 = X, \\
(m + \mu_{22})\ddot{v} + (mx_G + \mu_{26})\dot{r} + mnr = Y, \\
(mx_G + \mu_{26})\ddot{v} + (I_{zz} + \mu_{66})\dot{r} + mx_G ur = N, \\
\ddot{\xi} = u \cos \psi - v \sin \psi, \\
\ddot{\eta} = u \sin \psi + v \cos \psi, \\
\ddot{\psi} = r.
\]

- Comments:

1. The added masses can be estimated reasonably accurately
2. Is further simplification \((x_G = \mu_{26} = 0)\) possible? Yes but not desirable as long as \(x_G\) is usually known and the simplification is insignificant
3. Quasi-steady hydrodynamic forces must be estimated using minimum number of shape parameters with acceptable uncertainty (what is this?)
Quasi-steady forces \( F = X, Y, N \)

1. Holistic approach: \( F = F(u - u_0, v, r, n, \delta_R) \)
   a. Is typically associated with the Abkowitz (or similar) polynomials
   b. Advantages: all interaction effects are accounted for automatically, is structurally simple though with increased number of regression coefficients (model parameters)
   c. Disadvantage: no systematic databases have ever been created, existing collections are proprietary and partly lost \( \Rightarrow \) impossible to use the approach without preliminary tests/CFD computations for a defined hull form \( \Rightarrow \) hardly suitable for low-level methods

2. Modular approach: \( F = F_H + F_P + F_R \)
   a. Several database or Munk+cross-flow-drag methods exist for Hull forces
   b. The Propeller thrust (1 quadrant) can be estimated with the Oosterveld—Oossanen polynomials --- this is the simplest acceptable method
   c. The Rudder forces will be commented in a separate communication
Empiric methods for hull forces

- First empiric methods based on more or less systematic tests with scaled models of hulls appeared in 50—60s but nowadays, regarding merchant ships, methods of the MMG family are preferable.

- The latest version “Standard MMG method” (Yasukawa & Yoshimura 2014) presumes carrying out PMM tests in each case → unsuitable as low level method.

- Inoue et al. (1981): is 4DOF; the resistance curve is supposed to be known; sway and yaw forces represented with simple polynomials depend on C_B, several dimensionless combinations of the main particulars, and on the trim. Extended by Sutulo (1994) to 4 quadrants

- Matsunaga (1993): 3DOF, somewhat different nonlinear part, empiric shallow-water corrections

- Kijima (2003): additional geometric parameters describing the shape of the stern
Turns with empiric methods

35 deg helm

5 deg helm
Possibilities of empiric methods

- All existing empiric methods suffer from considerable uncertainties which is quite natural: compare with hull residual resistance databases. Increased complexity of the manoeuvring problem does not leave hopes for a different situation.
- For accurate predictions, CFD computations or model tests are necessary --- higher level methods.
- Is it possible, at least, to make low-level predictions of the hull hydrodynamic forces conservative? In theory---yes but in practice---unlikely: definitely, the margin will be too large.
- However, empiric methods provide qualitatively consistent results and can be used for standardizing purposes as long as the final criteria are faired with those observed on existing ships.
Estimation of aerodynamic forces

- A very old generic model:
  \[ C_{XA} = -C_{X0} \cos \beta_A, \quad C_{YA} = C_{Y0} \sin \beta_A, \]
Aerodynamic yaw moment

\[ C_{NA} = C_{YA} x'(\beta_A) ; \quad x'_A = \frac{x_{A0}}{L_{OA}} + \frac{1}{4} - \frac{|\beta_A|}{2\pi} \]
Conclusions

1. Low-level model of minimum complexity is 3DOF, with O&O propeller model (too simplistic formulae for, say, bollard pull must not be used), using some empiric method for the hull forces.

2. Modification of parameters for hydrodynamic hull forces aiming at guaranteeing conservative estimates is problematic.

3. However, apparently, a method for conservative (upper limit) estimation of aerodynamic loads can be devised.